Steam Consumption of Pumping Machinery

..BY..

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Henry Ezra Keeney

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering.

INTRODUCTION.

Those who have not considered the subject of water distribution, may not believe that pumping machinery stands at the head of the various branches of Engineering. As to the truth of this statement, we have only to consider that coal could not be obtained without the pumping engine; our water supply for boilers and our city water supply would be difficult of management if it were not for the pump. Water is found in every mine, to a greater or less extent, and the first applications of steam were for pumping the water out of these mines.

HISTORY AND DEVELOPMENT.

Many forms of pumps were used for obtaining water, but not until the 17th century was steam used for pumping water. So manifest was the economy of steam pumps over those driven by horses, (which were previously used to a great extent) even at the beginning, that they were introduced as rapidly as they could be furnished with the limited supply of tools at the command of the engine and boiler builders of that day.

Edward Somerset, second Earl of Worcester, proposed and probably made the first useful steam engine, and its use was for pumping water. There are no drawings and but a meagre description, so it is not known what the exact form of this first steam pump was, except that it was double acting. The inventor's account calls it a "Fire Water-work".

In 1698, the first successful steam pump was patented by

Thomas Savery. It worked somewhat on the principle of the modern Pulsometer. A serious difficulty, however, was the fact that it did not raise the water to a very great height, owing to the low steam pressure used. The waste of steam was also very great, as it was condensed upon the surface of the water and the sides of the chamber, at each stroke. It consumed, in proportion to the work done, about twenty times as much coal as our modern steam engines.

In 1705. Newcomen invented his Atmospheric engine. This was the first beam engine, the plunger being on one side of a beam, while the steam cylinder was on the other end. To this beam engine, Watt added a condenser to lower the steam consumption, and in 1769 received a patent on an engine which used steam on top of the piston, to force it down, instead of the atmosphere as in the Newcomen engine. He did this also with an idea of lowering the steam consumption. He seemed to see the need of keeping the piston and cylinder walls warm in order to prevent condensation. He soon after added the stuffing box in order to make the piston steam tight.

In 1814, Woolf introduced a compound engine into the mines of Cornwall. This was soon displaced, however, by Trevithick's single cylinder engine, which was less complicated and very economical. This engine, under the name of the Cornish pumping engine, was for many years famous for its economy. It is the earliest form that has an efficiency at all comparable with modern engines. The success of this type probably accounts for the almost universal tendency shown by builders to place a beam between the pump rod and the piston rod. It was only a comparatively short time ago that a change was made and the direct acting pump used.

C L A S S I F I C A T I O N .

To enumerate the various forms of pumping engines which have been constructed in the past, many of which have been famous, both for economy and capacity, would be quite impossible. A brief explanation of some of the peculiarities of a few large pumping engines and the prominent principles involved in their construction, will be sufficient.

Probably no large pumping engine in the past has had so large and merited a reputation as have the Cornish engines, when used for deep mine pumping. Their construction with the crude appliances at hand in those early days of engineering is a marvel.

The principles upon which Cornish pumping engines were designed and built were so well adapted to the purpose for which the engines were used, that up to the present time they have not been improved upon to any great extent. Of course, improvements have been made along other lines of use; but for pumping water from deep mines, the Cornish has not been much improved upon.

The principle upon which this engine is constructed is that steam within the steam cylinder, under varying conditions of expansion, is used to lift a weighted plunger, which, on descending, forces upward by its own weight alone, a column of water equal in weight to that of the descending plunger. The length of stroke of the piston and of the plunger is determined by the operation of its steam, equilibrium and exhaust valves.

The next class of large steam pumping engines which have played an important part in the history of hydraulic engineering, may be grouped together as Rotary Engines. What is meant by the term "rotative" engines, are those in which there are parts which make complete and continuous rotary motion and in which, in some way or another, there are used shafts, cranks and fly-wheels. Engines of this class vary greatly in design and details of construction. They are also of varying sizes, including some of the largest and most expensive in the world. As a general rule they are employed for supplying towns and cities with water, and, in some cases for pumping water from shallow mines. In this class of engines, the methods of applying the power of the steam to drive the pump plungers vary greatly, both in general design and details of construction. In some cases it is through the use of long and short beams, or bell cranks, sometimes through gearing and occasionally through the plunger or piston of the pump direct. In all cases, however, the limit of the stroke of the steam piston and of the pump plunger is governed by the crank on the revolving shaft.

Attached to the revolving shaft is a fly-wheel of greater or less diameter and weight. This fly-wheel, in addition to assisting the crank to pass the dead center at each end of the stroke, is employed to store up, at the beginning of each stroke of the steam piston, whatever excess of power or impulse there may be imparted to it, beyond that required to steadily move the water column. This power is given out again toward the end of the stroke, when the power of the steam, is, of itself, not sufficient to move the water column. In this respect, the function of the revolving fly-wheel on the rotary engine is the same as the weighted plunger in the Cornish engine, both being used to permit the steam in the steam cylinder to be cut off at a portion of the stroke, and to expand during the rest of the stroke.

The next class of pumps driven by steam are Direct Acting steam pumps. A direct acting pump is one in which there are no revolving parts, such as shafts, cranks or fly-wheels; pumps in which the power of steam in the steam cylinder is transferred to the piston or plunger, of the pump, in a direct line, and through the use of a continuous rod or connection.

In pumps of this construction, there are no weights in the moving parts, other than that required to produce sufficient strength in such parts for the work they are expected to perform. As there is no opportunity to store up power, in one part of the stroke to be given out at another, it is impossible to cut off steam in the steam cylinder during any part of the stroke. Uniform and steady action is dependent, in this class, upon the use of a steady and uniform pressure of steam through the entire stroke of the piston, against a steady and uniform resistance of water pressure in the pump. The length of stroke within the steam cylinder is limited and controlled by the admission, compression and release of the steam used in the cylinders.

Up to the time of the introduction of the direct acting steam pump, all other pumping machinery of the world, then in use, was the outcome of evolution. It had been developed by slow stages, in which one engineer after another, aided by the experience of others as well as himself, supplemented by his own inventive faculties, added here and there slight improvements, to which other engineers, with increased experience, were enabled to add still other improvements, so that each new engine was constructed under more favorable circumstances and with increasing expenditures, was supposed to excel all previously built. The direct acting engine, however, was invented by one man, and was, in the main, perfected during his lifetime.

To Henry R. Worthington is due the credit of building the first direct acting steam pump, in 1840 to 1844. Others have since patterned after this pump, and now the direct acting pump is the one in most universal use. The fact that steam could not be used expansively was one objection to this class of pumps, but this has been overcome in several different ways by the different pump manufacturers. Some of these methods will be described in connection with the descriptions of a few of the many pumps now on the market.

The advent of this direct acting pump was a matter of especial importance in the engineering world, inasmuch as it greatly simplyfied the construction and reduced both the weight and the cost of pumps. For many purposes and in small sizes, single cylinder pumps of this type give results entirely satisfactory. When considerable quantities of water are to be handled, however, calling for pumps of such size as to be called engines, the direct acting pump, with a single cylinder, is undesirable because steam must follow the piston practically for the full stroke and all benefits due to expansion are lost. This consideration led to the two-cylinder compound pumps in which expansion is obtained. But triple-expansion engines had proved themselves superior in ocean navigation and why should not the same results obtain in the instance of direct acting steam pumps? It would undoubtedly permit of greater expansive working which was desirable to the end of bringing greater economy in the use of steam. Economy is particularly desirable in the case of an engine likely to be operated at all hours of the twenty-four. Some companies make, now, a triple-expansion pumping engine for large capacities and they are found to be very economical, comparing favorably with the triple-expansion steam engines now used so extensively in marine service.

Descriptions of some of the modern high duty pumping engines.

The Gaskill Pumping engine at Kalamazoo, Mich., is a compound vertical engine, having both a beam and a fly-wheel. it is described in the American Machinist of May 15, 1886, as follows:- "The steam pistons travel simultaneously in opposite directions, and the valve action, although a modification of what is called the Corliss, has the same effect upon the steam distribution as the valve action of a horizontal engine. The engine was designed for the same service as an overhead beam engine. The steam cylinders being vertical the pumps can be placed at any desired distance below the engine room floor, in order to accommodate the engine to situations in which the water or source of supply has a fluctuating level. The pumps have single acting plungers, one being placed under each steam cylinder, with outside packing and separate valve boxes. However, double acting plungers can be used equally well.

The beam is of peculiar construction, being made with side pieces of heavy steel plate, with cast iron hubs bolted in, for the reception of center shaft and connecting rod pins. The main connecting rod pin is located on the lower side of the beam, at a point which secures the proper vibration of the shaft, which is placed quite close to the steam cylinder, this arrangement giving ample length of rod. The main crank shaft is located between bearings on the frame and two overhanging fly-wheels are keyed to the outer ends of the shaft.

The pumps are fitted with four sets of small single beat rubber valves, mounted in composition shells and working on composition seats, screwed into the diaphragms of the valve chamber. Each set contains ninety-one valves, or three-hundred and sixty-four valves in the suction and discharge chambers of both pumps. The valves are guided above by the stem (which moves with the disc) passing through the hub in a three-winged cage, which screws down over a threaded projection of the seat, outside the valve disc. The admission valves to the high pressure cylinder are double beat poppet valves. The exhaust valves to both the low and high pressure cylinders, and the admission valves to the low pressure cylinders, are ordinary slide valves. These valves are driven by means of eccentrics on a shaft which is driven from the main shaft through small bevel gears.

The pump at Milwaukee is a good representative of the pump built by the E. P. Allis Co. The description may be found in T. A. S. M. E., volume 15. It is three-cylinder compound engine of the rotative type, vertical, with receivers between the high and low pressure cylinders. Each steam cylinder operates a single acting, solid plunger pump, placed vertically underneath it in the well. The axes of the three steam cylinders and of the three pumps lie in the same vertical plane, in which, above the steam cylinders, lies the axis of the main shaft, which carries two fly-wheels, one over each of the two spaces between the three cylinders.

The valve gear is of the Reynols-Corliss type, and is adjustable. That of the high pressure cylinder, which is placed between the two low pressure cylinders, is regulated very effectively by a ball governor.

The receivers are cylindrical, with the horizontal axes parallel to the vertical plane containing the axis of the cylinders, pumps and main shafts, and are located behind the central, or high pressure cylinders, at about the elevation of the tops of those cylinders. The pump valves are of the Cornish double beat type, and there are seven suction and seven delivery valves in each pump.

A good description of the Worthington high duty attachment may be found in J. F. Halloway's lecture before the M. E. students, of Cornell University, Engineering News, of August 31, 1889. The Worthington pumping engine is made in New York, and is a direct acting engine, no fly-wheels or beams being used. The valves are of the Corliss type, with cut-off valves placed over them. Expansive working is secured by means of balanced cylinders placed on the frame between the steam and water ends, mounted on trunnions, and fitted with plungers attached to the crosshead of the engine at one end, and at the other subjected to a water pressure. During the first portion of the stroke, the plungers of these cylinders act in a direction to oppose the motion of the steam piston, but as the latter moves forward, these cylinders rotate on their trunnions, and act against the piston at a less and less advantageous angle, until at half stroke they exert their pressure at right angles to the motion of the piston, and so neither tent to impede nor accelerate it. Passing this point, however, the plungers begin to assist the motion of the piston and thus compensate for falling pressure in the steam cylinder. The result of this device is that the effective pressure of the pump plungers is maintained nearly absolutely constant throughout the whole stroke.

In the vertical Worthington, there is a balancing device below the compensating cylinders, which exactly balances the weight of the reciprocating parts. This consists of a cylinder through which the piston rod passes, and is provided with a piston to fit the cylinder. Below this piston is water, which, as the piston descends, is forced out of the cylinder through a pipe against a pressure of air. This air pressure forces water back into the cylinder again, and really lifts the weight of the reciprocating parts during the up-stroke.

The Griscom Steam Pump (for description see American Machinist, Jan. 3, 1889) has, thus far, been wholly used as a mining pump, but the principle is capable of adaptation to any service. Steadiness of operation is obtained by the design of the valve motion, the pump being constructed without connecting rods or fly-wheels. This construction also allows the pump to be run at a very high steed. The crosshead is attached directly to the piston rod, and motion is imparted to the steam valve by a motion block, which travels in guides, giving motion to a balanced crank, attached to a shaft, upon which is keyed a quick throw eccentric. By means of this eccentric, motion is imparted to a rotary valve, which is instantly thrown open, and remains open during seven-eights of the stroke, affording an economical use of steam. It is through this arrangement, or combination, together with the absence of a connecting rod and fly-wheels before referred to, that the makers are enabled to obtain the high speed which is characteristic of the pump. The plunger, water valves and seats are made of phosphor bronze, or gun metal, whenever required to withstand the acids usually found in mine water. For similar reasons, water barrels, water chambers and suction and discharge pipes are constructed of a peculiarly hard, close grained iron. It is not uncommon for these pumps to attain a speed of 200 to 250 feet per minute, without jar or shock, and throw a steady stream of water.

There is used in the mines of Minnesota, a mine pump built by the Buffalo Steam Pump Co. It is described in the American Machinist, of May 5, 1892. The high pressure cylinder is 12 inches in diameter, the low pressure cylinder, 22 inches, with a stroke of 18 inches, and 7-inch plungers. The rated capacity is 300 to 350 gallons per minute, delivered 600 feet above the station, with steam pressure at 65 lbs. in the steam chest. The plungers are tied together with steel tie-rods, coupled into cast steel crossheads, and carried through bronze lined stuffing box glands. The water passages have areas equal to 50% of the plunger areas. Each valve chamber contains three valves having areas also equal to 50% of the plunger area. Both the suction and discharge valves are overhead, so that the plungers are always water packed. The valves of the steam cylinders are of the ordinary plain slide valve type, and are arranged to run by ordinary duplex movement.

At the Jamaica Station of the Brooklyn Waterworks, there is a triple-expansion Davidson pump. The following description is taken from the American Machinist, of March 13, 1890. The cylinders are 9, 14 and 24 by 24. The low pressure cylinder is in the middle with the intermediate cylinder next to the pump, and the high pressure cylinder at the outer end. The exhaust from the high pressure cylinder is piped past the low pressure cylinder,to the intermediate cylinder. From this, the steam goes to the low pressure cylinder, from which it passes to the indepentent air pump and condenser. The arrangement by which the low and intermediate pressure cylinders are brought closer together is as follows: The rod of the intermediate cylinder carries a crosshead, and from near the outer end of this crosshead, two piston rods extend to the low pressure piston. These two rods pass through bronze sleeves, alongside the intermediate cyl inder, underneath the lagging, to the end of it. These sleeves are provided, at their outer ends, with ordinary stuffing boxes, which are entirely accessible. It is this feature that permits the low and intermediate pressure cylinders to be placed close together,thus providing stuffing boxes in plain sight, and at the same time saving space. From the piston of the low pressure cylinder, a single rod extends to the high pressure cylinder, these two cylinders being far enough apart to permit stuffing boxes to be placed between them. The steam valve is driven by means of a connection from the crosshead. There is only one valve in the steam chest, which may be described as a compound valve, inasmuch as its functions are two fold. This valve has a cylindrical faced and performs the duty of a slide valve proper and an auxiliary valve. The duty of auxiliary valves in direct acting steam pumps is to admit steam to small pistons, which, by their motion, move the main steam valve to and fro, so as to admit steam and exhaust it from the cylinder. The action and drawing of this valve will be described later in connection with the description of the small Davidson pump upon which tests were made. The valves are precisely the same. This arrangement, however, applies only to the intermediate cylinder of the triple expansion engine. The valves of the high and low pressure cylinders are plain slides, and are moved from the intermediate, the motion for the high pressure cylinder being reduced by means of a lever.

The engine built by the Nordberg Manufacturing Co., and set up at a station of the Pennsylvania Water Co., near Pittsburg, Pa., is one of the record breaking engines in the line of steam consumption. It is very fully described in "The Steam Engine at the End of the Nineteenth Century", by R. H. Thurston. (see A. S. M. E. volume 21) It is a four-cylinder, quadruple-expansion engine, built to operate under 200 lbs. steam pressure, and under a head of about 600 feet between the well and reservoir. The water pressure is, normally, about 275 pounds at the pumps. The capacity of this engine is six million U. S. gallons per twenty-four hours against a head of 620 feet.

The engine, self contained, rests on a large base plate, which also acts as a suction air chamber for the pump. This base plate rests directly on the country rock, there being no artificial foundation.

The pumps are double acting, with outside packed plungers, and rest on the base plate. Each pump is made of two castings, all four valves being arranged directly in line, one above the other, the plungers being arranged on one side of the valve chambers. The valves are of rubber, working on brass seats, and are arranged in polygonal cages, by which arrangement a minimum diameter of valve chamber is obtained.

In order to guard against breakage of the pumps, due to the high water pressure and other conditions, the pulsating chambers of the pumps are enveloped in steel casings. There are bolts passing through the pulsating chambers, which serve as anchorage for the plates or jackets in question. The jackets are made in halves, and the joints are made in the plane passing through the center of the cylinders. Strong set-screws placed in the jackets bear upon the ribs of the pump casting underneath, thus relieving this from the strain due to the water pressure. This arrangement is thought to be absolutely safe against breakages.

It is particularly important that the pumps should be very safe in this case, as the engine rests on the pump, and the valve chamber casings of the pumps are part of the engine framing. The valve chambers are extended on top to receive the engine bedplate, in which is the main bearing, and which supports the engine frame. A notable and unique feature of this particular engine is that the engine framing is placed in the center of the machine, extending from under the center of the cylinders, downward, with the running parts arranged outside the framing. There is only one main bearing, which extends clear across the engine bed-plate. There is a crank-disc on each side of this bearing, on the outside of which are clamped the two fly-wheels. On each crank-disc is a pin; the two pins are exactly in line.

The plunger rods are directly connected to the steam pistons. At the upper end of these rod connections, and immediately below the steam cylinders, are cross-heads keyed to the rods, which cross-heads project sidewise outside the engine frame, and are here formed into pins, which connect, by means of short links, to corresponding pins of the rockers; two each side of the engine, one driven from each side of cross-heads. Directly in line with the cross-head-pin and its corresponding pin on the rocker, this rocker is provided with a second pin which takes the main connecting rod and connects to the crank pin. These pins are located in such a position as to bring one side of the engine and one pump on the dead center, while the other side of the engine, with the other pump, is in the middle of its stroke. Each side of the engine carries two cylinders placed tandem; the high-pressure side the cylinders No. 1 and No. 3, the low pressure side the cylinders No. 2 and No. 4. The slides in the cross-head are formed in the engine framing.

The pins on which the rockers are supported are fastened stationary in the engine framing, the bearing being formed in the rocker itself. There are two connecting rods in the same plane, and thus one is forked at the crank-pin end, while the other one is single. The engine frame proper is located inside the piston rods. In order to get a proper support outside the piston rods, there are on each side two columns extending from the base plate at the bottom of the machine clear up to the low pressure cylinder, each column being carried through in an unbroken line; they are made of cast iron.

Between the engine frame and the low pressure cylinders are a second set of polished steel columns on the center lines of the cylinders, and spaced equally with the outside columns; thus the low pressure cylinders, resting on columns of their own, are entirely independent of the high pressure cylinders. A cross-bracing is arranged to give the low pressure cylinders additional stability.

The receivers are provided with tubular reheaters. These receivers are located between the cylinders, and mounted one upon another in such a manner as to reduce to a minimum the losses caused by radiation. In order to reduce to a minimum the heat conduction losses, the high pressure cylinders are provided with a number of projections, at the bottom ends, which rest on the framing, and leave quite a space between the body of the cylinder heads and the frame, which is filled out with non-conducting material; the only surface in contact with the cylinder and frame being the small surface of these projections or bosses.

All cylinders are steam jacketed on the barrels, only the high pressure cylinders being provided with separate liners; the low pressure cylinders having the jackets formed in one casing with the cylinders.

The valve gear is of the Corliss type, with the exception of the No. 4 cylinder valves, and the exhaust valve gear on No. 3 cylinder, in which single beat poppet valves are used in order to reduce clearance to a minimum. The cut-off is variable on all cylinders, except on No. 4; the high pressure cut-off being under control of a centrifugal governor. As the cylinder ratio between No. 2 and No. 1 cylinder is comparatively small, and a low degree of expansion is carried on in the high pressure cylinders, a special valve gear had to be designed and used in these cylinders, by which steam can be cut off after half stroke. The ratio between No. 3 and No. 2 cylinders is so great that steam can be cut off before half stroke, and an ordinary Corliss valve gear was used on this cylinder. The ratio between No. 4 and No. 3 is small; steam in No. 4 had to be cut off at about three-quarters, thus requiring no special cut-off mechanism, or trip releasing gear.

The valves are operated by two revolving lay shafts, one on each side of the machine. With the construction of the crank shaft, it was not easy to arrange eccentrics on this shaft, from which to operate the valve gears. A rotating gear was therefore used to transmit the rotation of the crank shaft to the lay shaft. From one of the lay-shafts, the governer is driven by a belt.

In the test of this engine a surface condenser of the marine type was used. The water passed through the condenser three times, entering at the bottom and leaving at the top.

DESCRIPTIONS OF TYPES OF PUMPS ON WHICH TESTS WERE MADE.

Tests were made on four pumps in the Mechanical Engineering Labratory, of the University of Illinois, the results of which are submitted. The following descriptions are those given by the manufacturers in their catalogues.

The Marsh pump is size D 5 x 3 x 3 1/2, 100 horse-power. The two cylinders and the base form a single casting. In these descriptions reference is made to the sectional drawings. The directions in which the steam passes are shown by the arrows. (Plate 1)

The steam entering the chest is passing to the left, through the annular opening formed between the reduced neck of the valve and the bore of the first chest wall. It is thus projected against the inside surface of the valve head before escaping through the port and passing through the cylinder.

Both the pressure and impulse due to velocity, acting on the valve head, operate to close or restrict the admission portage at the annulus, by forcing the valve to the left, or in the direction of the current. On reaching the cylinder, and driving the piston forward, that is toward the right, the reactive effect of the cylinder steam upon the opposite side of the valve head , entering the outer end of the chest chamber, is pressing the valve toward the right--a movement which would give the admission more portage, and deliver more steam to the cylinder. The valve then holds a position depending upon the relative strength of the two forces which tend to move it in opposite directions--admission steam and cylinder steam--the former tending to close the valve, the latter tending to close it. This constitutes the governing element of this pump.

The steam piston consists, as shown, of a spool form, each head of which is provided with a metal packing ring; the interior space forming a reservoir for live steam, which is supplied from the upper chamber of the chest above the valve following the passage indicated by the dotted lines. The hole is vertical, and the lower end is always within the cavity enclosed between the piston rings. This pressure is used only for the purpose of tripping, or reversing, the valve, by admitting steam alternately against the outer surface of the valve heads, through the connecting passages near each end of the cylinder.

If required to handle cold water, these pumps are provided with exhaust deflecting valves, which permit the exhaust from the steam cylinder to enter the suction chamber, where it is combined with the water being pumped, warming it, and then passing it into the boiler with the feed water.

These pumps are operated with the "Marsh Patent Self-Governing Steam Valve", which automatically regulates the speed of the piston under any conditions.

Each water valve consists of a cup shaped valve, with central guiding pin, and a girded seat supporting a disc. This disc is slightly larger than the aperature through the seat, and serves to deflect the water pumped, instead of allowing the valve to do so. It also cushions the downward action of the valve by displacing a portion of the water entrapped in the cup, which it enters in closing. The fluid, therefore, has power to raise the valve as high as the disc only. No stop is needed to limit the lift, and easy action is insured both ways. In cases where water contains grit or sand, metal valves will not seat properly, and a composition disc of special construction soft rubber is provided.

The Deane pump (shown in Plate 11) tested was their No. 3 type, 5 x 3 1/2 x 7. The Dean single acting pump, it is claimed, will not stop or race, and can be depended upon under any and all conditions. They are suitable for pumping clear liquids for any service requiring a pressure not exceeding 150 pounds. They are fitted for either hot or cold water, or for other liquids. The valves are of rubber or metal as required.

The lever, shown in the drawing, which is carried by the piston rod, comes in contact with the tappit near the end of its motion and, by means of the valve rod, moves the small slide valve which operates the supplemental piston. This supplemental piston, carrying with it the main valve, is thus driven over by steam, and the engine is reversed. If, however, the supplemental piston fails accidentally to be moved, or to be moved with sufficient promptness by steam, the lug on the valve rod engages with it and compells its motion by power derived from the main steam engine.

In none of the so-called direct acting steam pumps is a rotary motion developed by means of which an eccentric can be made to operate the valve. It is therefore necessary to reverse the piston by an impulse derived from itself, at the end of each stroke. This cannot be effected in an ordinary single valve engine, as the valve would be moved only to the center of its motion, and then the whole machine would stop. It is general, therefore, to provide a small steam piston to move the main valve of the engine.

The M. T. Davidson pump tested was of size number 1, 3 1/2 x 2 x 4. (shown on Plate 111) It is a direct double acting pump with single steam end. The steam and water cylinders are rigidly connected by a frame called the intermediate. The intermediate carries a slide for the crosshead, preventing vibration and keeping the pump in line. The stuffing boxes of the steam and water cylinders are secured to the heads of the intermediate. The valve gear consists of only one valve, which is actuated by a positive mechanical connection with the main piston rod of the pump, being assisted in its movements by steam. The drawing shows the valve gear in detail. It consists of a cylindrical steam chest, M, which is bored out to make the face for the valve A, and the piston B and B' that assists in operating the valve. The pistons are connected, sufficient space being left between them for the valve and steam ports. They are also attached to the slide valve, all working in the same plane and being of the same diameter, insuring evenness of wear and readiness of access for adjustment, repairs etc. The valve is controlled and operated by the cam C acting on the steel pin D, passing through the valve into the exhaust port, in which the cam is located. In addition to this mechanical operation, steam is alternately admitted and exhausted from the steam chest by ports e and e', assisting the movements of the valve by steam actuating the valve pistons B and B'.

When the pump is at rest, the valve completely covers the main steam ports f and f', the cam holds the valve so that steam will be admitted to one end of the chest, and exhausted from the opposite end, by the ports e and e', throwing the valve and opening the main ports f and f', admitting steam to and exhausting from the steam cylinder. If the valve occupies any other position, one of the main steam ports will be open to steam and the other to the exhaust, insuring the direct supply of steam to one end of the cylinder and the rapid release of exhaust steam from the other end. In consequence of this, there can be no dead point, and the pump will start from any position.

When one of the main steam ports, as f, is completely open, admitting steam to the cylinder, driving the main piston, cam and valve in directions shown by the arrows, the first movement of the cam will be to oscillate the valve preparatory to bringing it into proper position before the opening of the auxiliary steam port e, to live steam, and e' to exhaust, and secondly to bring the valve to its closure (mechanically) slightly before the end of the stroke of the main piston, thereby causing slight cut-off and compression, next fully opening the auxiliary port e to steam, and e' to exhaust. The admission of steam to one end of the valve piston and the other being open to exhaust, throws the valve in the direction shown by the arrow, admitting and exhausting steam to and from the cylinder for the return stroke. The pistons are prevented from striking the cylinder heads by virtue of the mechanical valve closure.

In the small Blake pump tested, (shown in Plate 1V) a supplemental piston is used for driving the main valve. This main piston which controls the admission and exhaust of the main cylinder, is divided into two parts, one of which, C, slides upon a seat on the main cylinder, and at the same time affords a seat for the other part, D, which slides upon the upper face of C. As shown in the drawing, D is at the left hand end of its stroke, and C at the opposite, or right hand end of its stroke. Steam from the steam chest, J, is therefore entering the right hand end of the main cylinder through the ports E and H, and the exhaust is escaping through the ports H', E', K and M, which causes the main piston, A, to move from right to left. When this piston has nearly reached the left hand end of its cylinder, the valve motion moves the valve rod P, and this causes C, together with its supplemental valves R, S S' to be moved from right to left. This movement causes steam to be admitted to the left hand end of the supplemental cylinder, whereby its piston, B, will be forced toward the right, carrying D with it to the opposite, or right hand end of its stroke; for the movement of s closes N, the right hand steam port, and the movement of s' opens N', the left steam port, at the same time the movement of V opens the right hand end of this cylinder to the exhaust, through the exhaust ports x and z. The parts C and D now have positions opposite to those shown in the engravings, and steam is therefore entering the main cylinder through the ports E' and H', and escaping through the ports H, E, K and M, which will cause the main piston, A, to move in the opposite direction.

M E T H O D   O F   T E S T I N G .

The method of testing the pumps in the labratory of the Mechanical Engineering Department was as follows:-

The exhaust from the pump was attached to the condenser and the condensed steam weighed, thus getting the amount of steam used.

The water to be pumped was weighed in a tank on the floor of the labratory, and then run into a large storage tank in the basement, from which it was pumped. The level of the water in the storage tank was kept as nearly constant as was possible, thus making a constant lift.

A pressure gauge was placed on the discharge chamber of the pump, and the delivery pressure read at intervals. The other readings taken were the boiler pressure and strokes per minute of the pump, water used and weight of steam condensed.

The tests were nearly all of two hours duration, and two tests were made on each pump, with different delivery pressures. The steam consumption per horse power hour is based upon the water horse power, obtained from the total lift (delivery pressure reduced to feet, plus the actual lift) and the amount of water pumped per minute.

The arrangement of the apparatus used is shown in section on Plate V.

R E D U C T I O N   O F   S T E A M   C O N S U M P T I O N .

As shown in the results obtained, the steam consumption per horse power of these small pumps is very great. The horse power is so small, however, that the total steam consumption is not so large.

It is possible that the steam consumption might be reduced. Pumps of small horse power, such as those tested, may be compounded, and where they are used as boiler feed pumps, or some similar purpose, their entire cost is saved in a little over a year in saving of fuel, over that required by a simple pump of this type.

It is a well known fact that a compound steam engine uses less steam than a single one. The same must be true of a pump, which is run nearly every hour of the twenty-four.

If it were possible to place a fly-wheel on these pumps, a saving of steam might be made by using expansion. It would be difficult, however, to do this, and it is a question whether it would be practical or not.

FORM OF LOGS OF PUMP TESTS.

MARSH PUMP.

Strokes per min.	Delivery Pressure	Boiler Pressure	Water used lbs.
72	64	106	730
76	63	106	740
68	61	105	735
72	67	104	740
74	61	105	740
65	60	97	756
70	37	105	725
72	72	105	730
68	78	110	740
64	60	104	723
62	64	106	736
64	72	110	741
64	56	109	739
56	78	105	741
62	69	103	758
60	72	106	735
44	104	105	720
56	70	105	
54	80	105	
56	78	102	
56	79	104	
56	80	105	
54	82	105	
54	87	106	
50	80	104	
46	68	102	
40	94	104	
52	68	102	
52	68	102	
50	72	102	
50	70	103	
50	78	105	
50	64	105	
50	56	102	
50	60	101	
48	50	105	
56	72	109	
52	80	110	
52	85	112	
50	80	101	

R E S U L T S O F T E S T S .

Name of pump tested	Marsh	Marsh	Deane	Deane	Davidson	Davidson	Blake	Blake
Average delivery pressure lbs.	13.9	70.99	89.37	116.07	72.74	9.46	5.26	24.5
Actual lift in feet	6.79	6.79	6.875	6.875	7.375	7.375	8.00	8.00
Total lift in feet	20.69	170.35	212.77	274.3	174.96	29.38	19.78	64.48
Average boiler pressure	111.5	104.8	108	101	109	108	111	105
Average strokes per min.	99.87	57.7	50	60.2	50	105	114	62.6
Water per min lbs.	164.55	104.4	66.648	119.708	16.5	64.6	183.65	100.8
H.P. based on water pumped	.1	.538	.46	.995	.0874	,0575	.121	.196
Steam per H.P. per hour lbs.	600	237.8	572.35	309	715.1	723.5	735.5	418.3

A comparison of the results of tests on modern high duty pumping engines is shown in the table in plate VI.

R E F E R E N C E S T O L I T E R A T U R E O N

H I G H D U T Y P U M P I N G E N G I N E S .

621.64

C.M. 10:224 -- July 1896 -- American Practice in the use of Steam for Pumping Water.-- W. Kiersted.

E.N. 22:603 -- December 28, 1889. -- Performance of the Best Modern Pumping Engines, Compared to that of the Cornish Pumping Engine, of 1840. -- J. E. Denton.

The Steam Engine. A Treatise on Steam Engines and Boilers. -- D. K. Clark. 3:273.

621.641

A.S.M.E. 11:241 -- 1890 -- How to use Steam Expansively in Direct Acting Pumps. -- J. F. Holloway. Worthington method.

A.S.M.E. 13:83 -- 1891 -- Brooklyn Pumping Engines of 1860. -- M. Elroy.

P.I.M.E. :248 -- 1863 -- Description of the Cornish Pumping Engine with Wrought Iron Beam. -- Wm. Howe.

Power 16:10 -- October, 1896 -- Thirty-Million-Gallon Hammond Water Works Engine at Buffalo, N. Y. Describes Lake Erie Pump.

Power 17:8 -- August 1897 -- The Pumping Engine at the New High Bridge Pumping Station, New York City. Describes Blake Pump.

A.M. 6:42:2 -- October 20, 1883 -- Dean Brothers' Steam Pumps.

A.M. 8:14:7 -- April 4, 1885 -- Three Cylinder Compound Pumping Engine at Allegheny City, Pa.

A.M. 15:18:7 -- May 5, 1892 -- New Compound Condensing Mine Pump.

Buffalo Steam Pump Co.

A.M. 12:1:1 -- January 3, 1889 -- Griscom Duplex Steam Pump.

A.M. 13:11:1 -- March 13, 1890 -- Triple-Expansion Direct-Acting

Pumping Engine. Describes Davidson Pump.

E.R. 33:312 -- April 4, 1896 -- The New Pump at the Lewiston Water

Works. Description of new design of Dean pump.

E.R. 28:203 -- August 26, 1893 -- The Worthington Engine at Con-

cord, N. H.

A.M. 9:15:1 -- April 10, 1886 -- Worthington High Duty Engine. Des-

cribes action of oscillating cylinders.

A.M. 12:33:1 -- August 15, 1889 --Worthington High Duty Vertical

Pumping Engine. Describes pump at Memphis, Tenn.

E.N. 15:405 -- June 26, 1886 -- Description of the Worthington

High Duty Pumping Engine.

Power 18:4 -- April, 1898 -- The New Pumping Engines and Boilers at

the Ridgewood Station of the Brooklyn Waterworks.

Describes Worthington Engine.

E.N. 22:199 -- August 31, 1889 --The Worthington High Duty Attach-

ment and How it Works. Lecture by J.F.Holloway.

A.M. 9:20:1 -- May 15, 1886 -- The Gaskill Pumping Engine at Kala-

mazoo, Michigan.

E.N. 11:195 -- April 26, 1884 -- The Holly-Gaskill Pumping Engines

at Saratoga, New York.

A.S.M.E. 15:313 -- 1893-1894 -- On the Maximum Contemporary Econo-

my of the High-Pressure Multiple-Expansion

Steam Engine. Gives description and results of

tests on the Allis Pumping Engine, at Milwaukee.

Power 16:4 -- April, 1896 -- Record Breaking Pumping Engine at

Chester Hill Pumping Station, Boston, Mass. Describes Leavitt Engine.

E.R. 39:189 -- January 28, 1899 -- Possibilities of Economy in Pumping Engines. G. H. Barnes. Results of tests given.

621.643

A.S.M.E. 9:476 -- 1888 -- Duty Trials of Pumping Engines.--J.S.Coon.

A.S.M.E. 11:654 -- 1890 -- Standard Method of Conducting Duty Trials of Pumping Engines. Report of Committee.

A.S.M.E. 12:530 -- 1891 -- Duty Trials of Pumping Engines. Revision of first report, of 1890.

Power 19:7 -- July, 1899 -- Triple Expansion Pumping Engine for the Cleveland Water Works. Results of tests on an Allis engine.

R.G. 32: 113 -- February 23, 1900 -- A Pumping Engine Test. Snow Engine at Indianapolis, Indiana.

E. Mag. 24:428 -- The Gaskill Compound Pumping Engine.-- J. W. Hill. Engine at Evansville, Indiana.

E.M. 19:110 -- February 18, 1888 -- Report on the Duty and Capacity. Tests on the Gaskill Pumping Engine, at Spring Garden Pumping Station, Philadelphia, Pennsylvania.

E.R. 32:476 -- November 30, 1895 -- Tests on the Detroit Pumping Engine. Allis Engine.

E.R. 29:5 -- December 2, 1893.-- Test on the Allis Pumping Engine. R. C. Carpenter. Test at Milwaukee.

E.N. 28:213 -- September 30, 1897 -- Test of a 3000000-Gallon Pumping Engine at Buffalo, N. Y. Lake Erie Engine.

E.R. 39:310 -- March 4, 1899 -- Same.

E.R. 35:298 -- March 6, 1897 -- Same.

E.R. 30:344 -- October 20, 1894 -- Test of the Louisville Pumping Engine. Leavitt type.

A.S.M.E. 16:169 -- 1894-1895 -- Same.

Eng'g L. 53:194 -- February 12, 1892 -- Worthington High Duty Pumping Engine. Exhaustive tests.

A.S.M.E. 12:975 -- 1891 -- Performance of a Worthington Pumping Engine.--J. E. Denton.

E.R. 19:50 -- December 22, 1888 -- Report of Trials of a Worthington High Duty Pumping Engine at the West Middlesex Water-works, Hampton, Eng.

A.S.M.E. 21:-- 1899 -- Test of Two Ten-million-gallon Pumping Engines, at Baden Pumping Station; St. Louis Waterworks, June, 1899. Allis Engine.

Technograph 13:62 -- 1898-1899 -- Duty Trial of the Aurora High Duty Pumping Engine.--Prof L. P. Breckenridge.

Power 19:9 -- September, 1899 -- Quadruple Expansion Pumping Engine, Wildwood Station, Pittsburg, Pa. Nordberg Engine.

Eng'g L 68:150 -- August 4, 1899 -- Test of a Nordberg Pumping Engine. Pittsburg Engine.

E.R. 29:109 -- January 13, 1894 -- Test of a Pumping Engine at Birmingham, Alabama, Waterworks. Knowles Pump.

E.R. 36:145 -- July 17, 1897 -- A 22000000-gallon Triple-Expansion Pump at Philadelphia. Duty Trial.

A.S.M.E. 16:49 -- 1894-1895 -- Trial of a Vertical Triple-expansion Condensing Pumping Engine at the Trenton Waterworks. Results of Tests.

E.R. 28:189 -- August 19, 1893 -- The Performance of a Triple-Expansion Pumping Engine, With and Without Jackets. Tests at Lakewood, Ohio.

A.S.M.E. 11:328 -- 1889-1896 -- On the Influence of the Steam Jackets on the Pawtucket Pumping Engine.--J. E. Denton.

C O N C L U S I O N .

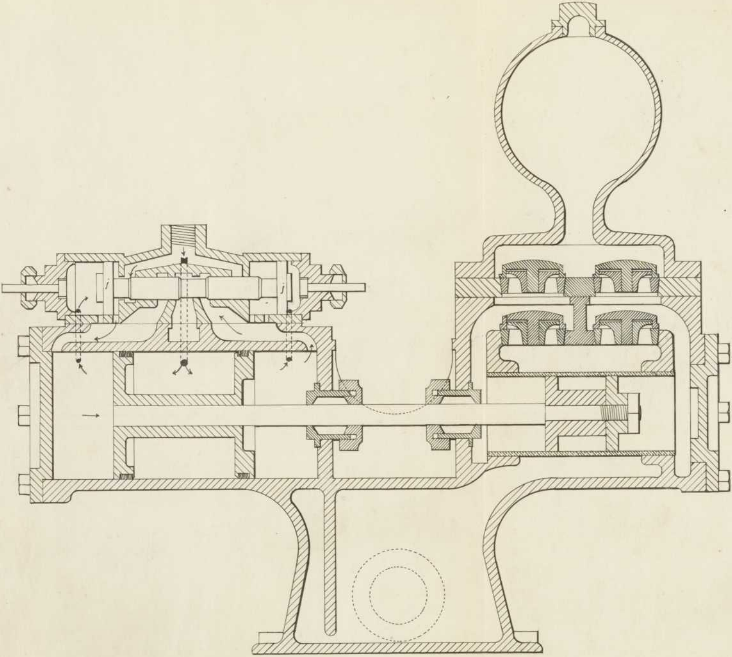
"Summarizing, we may state that the limit of progress attained to date is variously measured by these figures:

Approximate data in best practice.

Duty on basis of 1,000,000 B.T.U. footpounds ---------	163,000,000
Economy measured in B.T.U. per hour per H.P. ---------	11,160
Economy measured in B.T.U. per H.P. per minute -------	186
Economy, pounds steam at 1000 B.T.U. per hour --------	11.16
Economy in best fuel 15000 per lb, boiler at 80% efficiency pounds per hour ------------------------------------	1

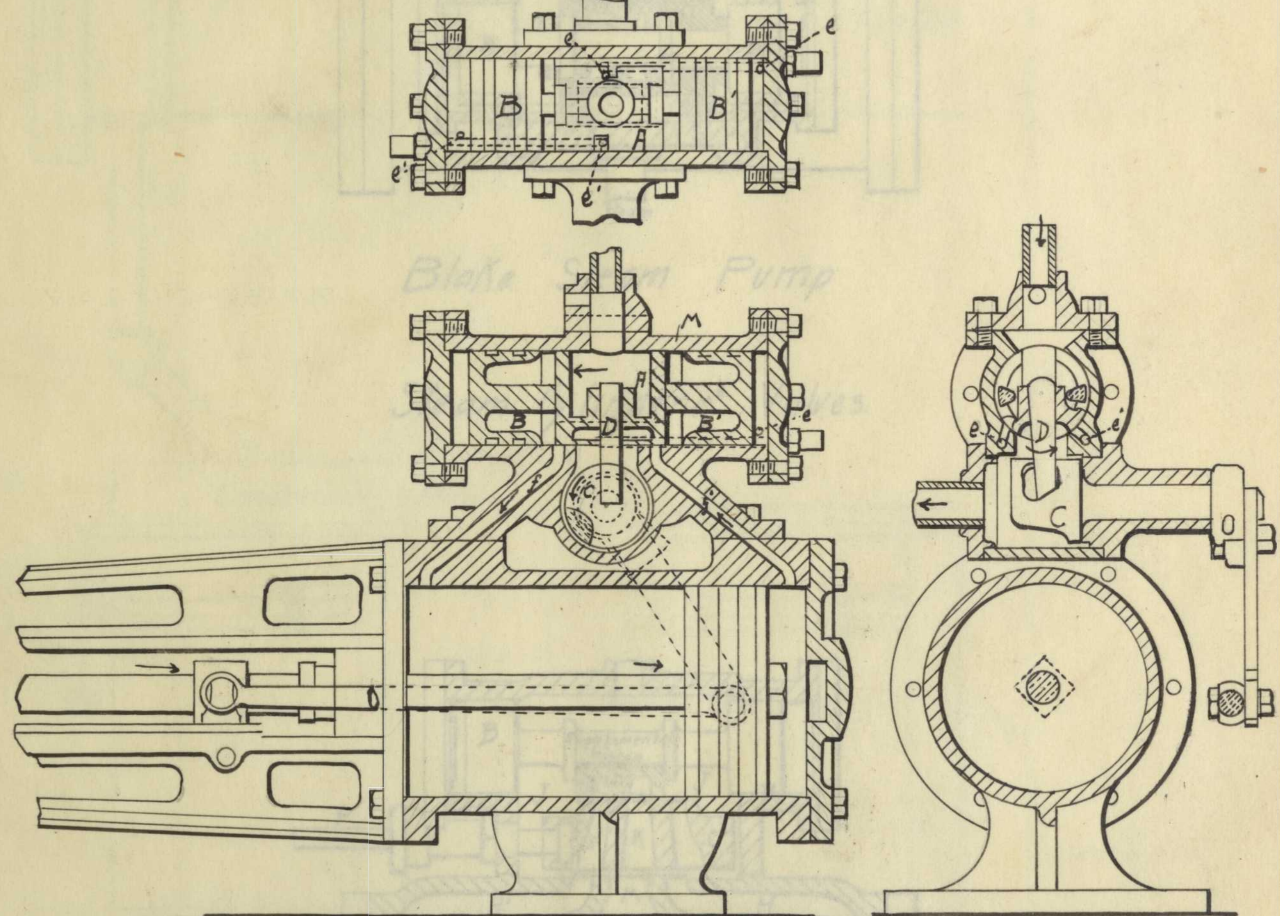
"Reviewing the history of the growth of this form of steam engine, it will be seen that its progress has illustrated that of the machine in all its forms, and that the steam pumping engine gives the engineer a record of greater extent and of more representative character, as exemplifying the evolution of the machine, than does any other type. The steam engine has now been so far perfected and the practical limits of pressure are coming to be so nearly approached by steam boiler constructers and users, that but little more can be expected of the designer; and even with the costlier types of engines, practically justifiable with exceptionally high cost of fuel, uninterrupted working and low values of money, as in some instances with the steam pumping engine, commercially practical progress seems likely to prove very slow henceforth."

PLATE I.



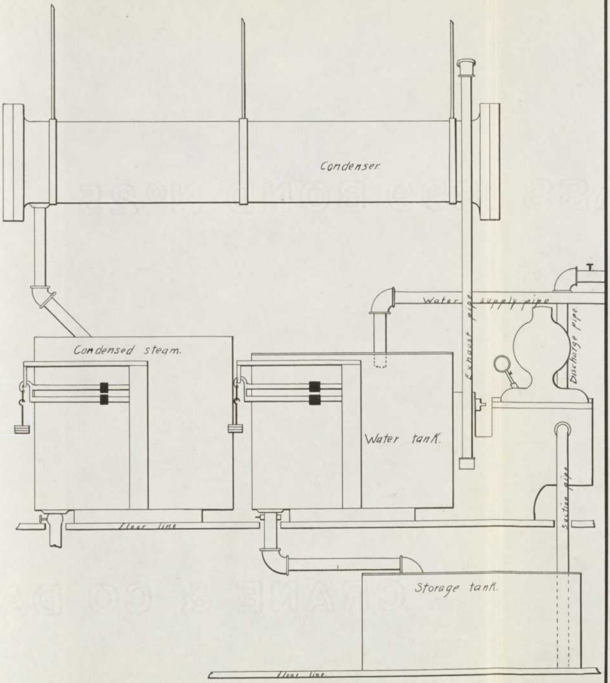
Marsh Steam Pump. Sectional View.

PLATE III.



M.T. Davidson Steam Pump. Valve Gear.

Arrangement of Apparatus for Tests. PLATE V.



RESULTS OF TESTS

OF

REPRESENTATIVE HIGH DUTY PUMPING ENGINES.

PLATE VI.

Style.	WORTHINGTON	WORTHINGTON	ALLIS	ALLIS	ALLIS	ALLIS	GASKILL	LAKE ERIE	LEAVITT	LEAVITT	KNOWLES	SNOW	NORDBERG	NORDBERG
Location.	SWARTOUT. N.Y.	MEMPHIS.	MILWAUKEE.	ST. LOUIS.	DETROIT	CLEVELAND	KALAMAZOO	BUFFALO	CHESTER HILL	LOUISVILLE	BIRMINGHAM	INDIANAPOLIS	PITTSBURG	AURORA
Date of test.	1891	1889	1893	1899	1895	1899	1886	1897		1894	1893	1898	1898	1898
Expert conducting test.	J.E. DENTON		R.C. CARPENTER	J.A. LAIRD	G.H. BARRAS		J.W. HILL	G.H. BARRAS N. CARLTON	E.F. MILLER	G.H. BARRAS F.W. DEAN	G.H. BARRAS	W.F.M. GROSS	R.C. CARPENTER	L.P. BRECKENRIDGE
Number of cylinders.	2	4	3	3	3	3	2	3	3	2	4	3	4	3
Diameter of Cylinder No. 1. Inches	33	30	28	30	28	34	18	37	13.7	27.21	30	29	19.5	16
Diameter of Cylinder No. 2. Inches.	66	30	48	54	48	62	36	63	24.37	53.13	30	52	29.5	28
Diameter of Cylinder No. 3. Inches.		60	74	80	74	92		94	39		60	80	49.5	39
Diameter of Cylinder No. 4. Inches.		60									60		57.5	
Diameter of Pump cylinder. Inches.	9.25	27	32	25.5	36	34	20.03	42	17.5	34 & 27	24	33	14.75	12
Diameter high pressure piston rod. In.	5.5	5.625		4			3.437	5		6			4.625	2.9375
Diameter low pressure piston rod. In.	5.25	5.75		4			2.625			5.5			3.875	2.9375
Travel of engine piston. Inches.	37.84	49.94	60	60	60	64	30	60	72	120	36	60	42	36
Average clearance cylinder. No. 1. %	2.51			10.36			2.5	1.42				1.7	1.25	
Average clearance cylinder No. 2. %	1.875			1.18			2.5	1.22				2.2	1.3	
Average clearance cylinder No. 3. %				.509				1.02				2.5	.55	
Average clearance cylinder No. 4. %													.36	
Average steam pressure at boiler. lbs.	89.	110.06				149.4	72.06			154.6	91		199.87	132
Average steam pressure at engine. lbs.	88	105.16	121.45	136			71.287	156.1		145.75				129.99
Average delivery pressure. lbs.	86.9	95.67									169.6	89.2	258.12	77.93
Average R.P.M.	20.14	16	20.31	16.44		18.72	26.52	21.54		18.57		21.18	36.52	43.19
Average I.H.P. of steam end.	436.7		568.668	548.71	573.7	770.44		1185.5	575.7	643.4	477.3	782.9	712.18	
Average M.E.P. high pressure cylinder.	34.08			55.6				58.96		59.91				
Average M.E.P. intermediate cylinder.				15.43				18.37						
Average M.E.P. low pressure cylinder.	9.02		21.77	61.15				11.55						
Temperature of feed water. F°	148.5		97	103.2			168.34	88			111	58.8	42.65	84.9
Per cent friction.			9.2		10.2	6.28			10.5			4.6		
Steam per H.P. hour. Engine alone.			10.61		10.93				9.3			10.08		
Total steam per hour. lbs.	7481									7864.7		10693.1	8732.4	3448.1
Number lbs. steam per H.P. hour.	16.99		11.678	11.627	12.52	11.451		11.82	11.22	12.2		11.26	12.263	
Duty per 1,000,000 B.T.U.	109,500,000		137,656,000	143,404,000	129,700,000			141,848,464	144,500,000	137,565,000	60,043,664	147,500,000	162,948,824	123,215,400
Duty per 100 lbs. dry coal.	116,530,000		139,000,000	160,455,000			102,728,884			132,237,500				
Duty per 1000 lbs. dry steam.			154,048,704		142,400,000	162,045,000		158,600,926	154,900,000	148,655,000		163,200,000	150,254,138	139,368,938
Duty per 1000 lbs feed water.		117,325,000	152,448,000			161,687,714								
Capacity – gallons per 24 hours.		11,202,000	18,000,000	6,548,103.25					20,300,000			20,000,000	6,225,052	